Bayesian inference of uncertainties in physics models from experimental data from the NIF

Current approach, example applications, and future aims

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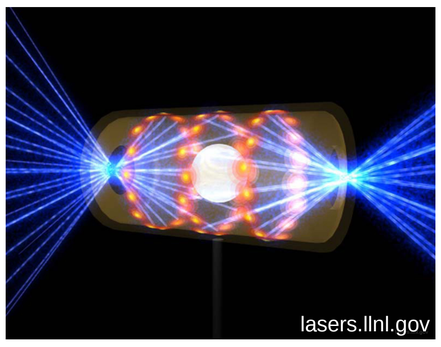
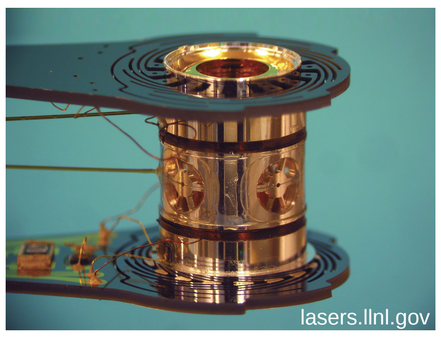
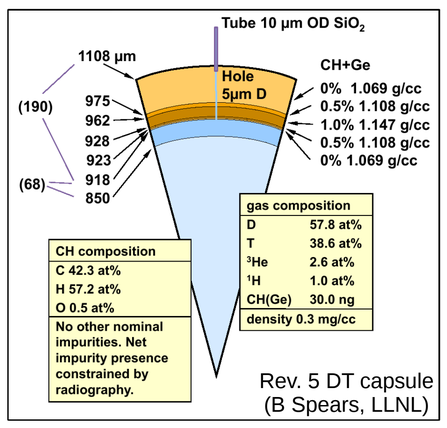
Inertial Confinement Fusion experiments at the National Ignition Facility

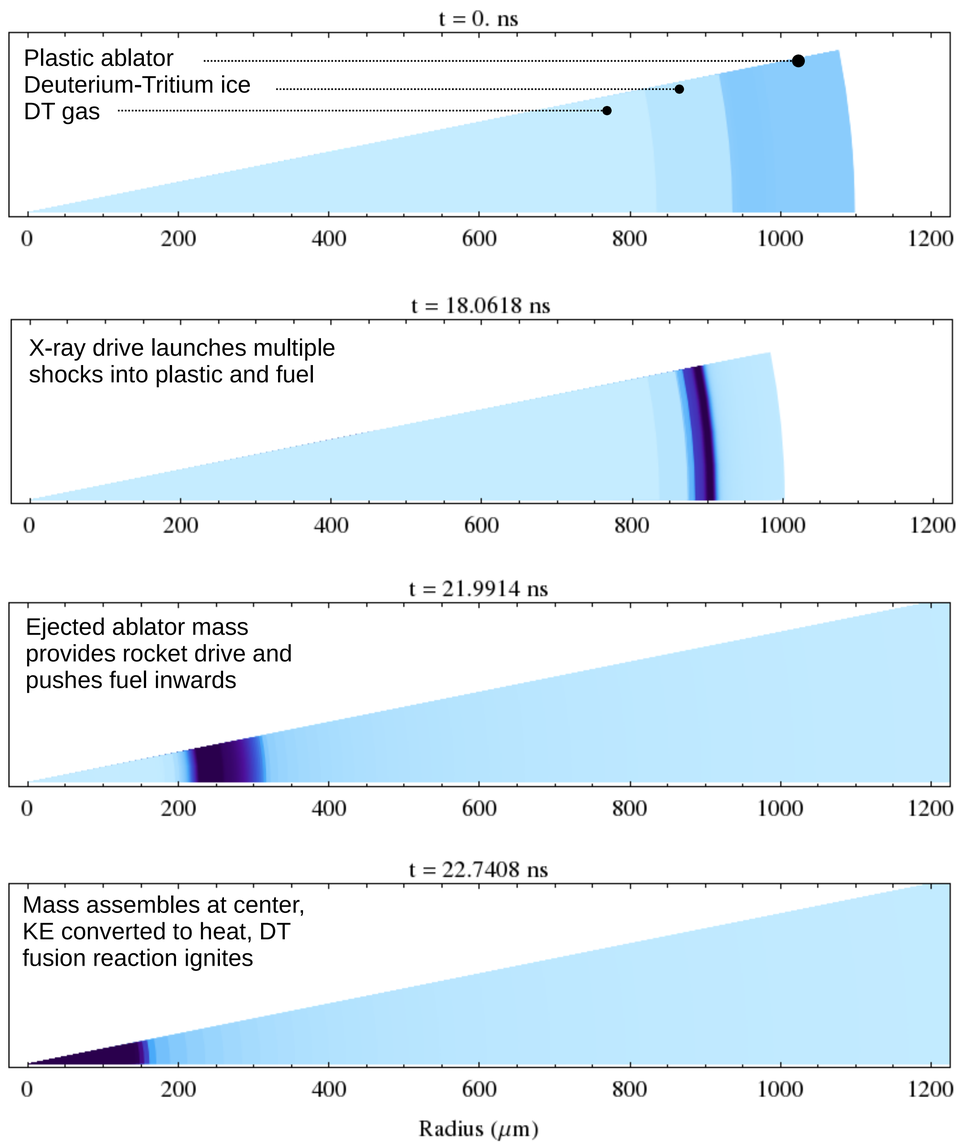
• ICF experiments aim to implode plastic capsules filled with hydrogen fuel, heating and compressing to the extreme conditions required for energy production by nuclear fusion







Rev. 5 DT capsule
(B Spears, LLNL)

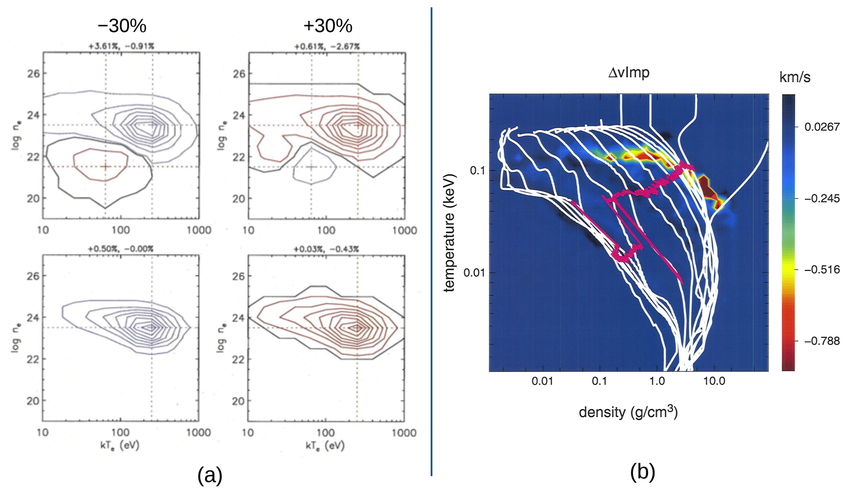


• The design and analysis of these experiments requires complex simulations that describe many physical processes over huge ranges of their parameter spaces

“Microphysics” models play a key role

• Multiphysics simulations are unable to correctly describe data collected from recent experiments

• These data are known to be sensitive to underlying physics models, which in turn may be inaccurate



Above : Contours of velocity during the rocket-like implosion stage, as a function of (a) the position of a modifier to underlying atomic physics models (courtesy C. Mauche, LLNL) and (b) a modifier to the equation of state of the ablator material (courtesy D. Clark, LLNL)

• There are other important factors:
  • Huge number of experimental parameters that can effect observed data
  • Large body of previous work on each peice of underlying physics

We aim to develop a consistent and reliable method of analyzing experimental data with respect to underlying physics models

• Model uncertainties
• Actual source of code/experiment discrepancy
• Further work with highest leverage

Statistical Approach

• Bayesian approach allows the importance of (relatively) noisy NIF experiments to be gauged against previous focused microphysics research

• Very large space of important experimental and model parameters is reduced by treating many using a prior-predictive model and the linear response of the multiphysics code

•This is framed as a modified χ^2 function :

Posterior on physical parameters θ

“Nuisance parameter” Modification

$$I(\theta|d_{exp}) = \sum_i \frac{(d_{exp,i} - d_m(\theta)_i)^2}{\sigma^2_{exp,i}} - (d_{exp} - d_m(\theta))^T \beta^T \beta (d_{exp} - d_m(\theta)) + \frac{1}{2}\ln\left(|\Lambda_\eta||\alpha^T\alpha|\right) - \ln P(\theta)$$

Standard χ^2

Prior

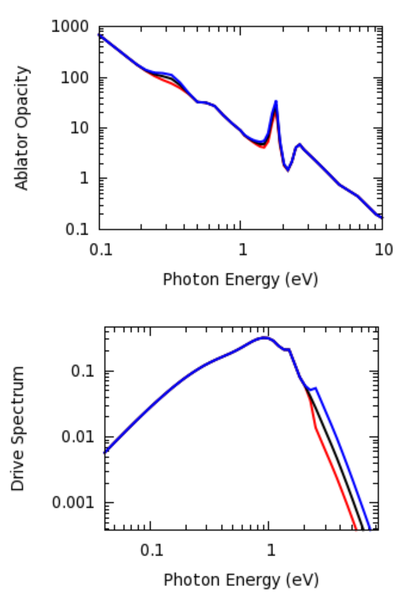
• We use a genetic algorithm to explore this function in a space defined by a set of multipliers on the values of physical quantities

•These multipliers are interpreted as the implied error on the underlying physical models

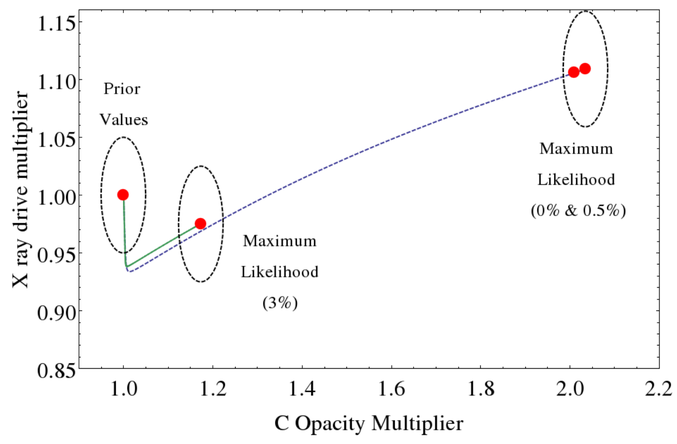
Application to atomic physics in the ablator plastic

• Simple models relate experimental data to radiation absorption and transport in the outer capsule shell

• Underlying atomic physics is difficult and relies on large first-principles calculations



• Modifiers placed on the ablator opacity, X-ray drive spectrum, and drive timing (not shown) mock up errors in underlying physics



• Prior confidence in microphysics models plays an essential role

• This is true even for prior distributions far from our most conservative estimates

• Variations in nuisance parameters, although individually negligible, add up to have a significant effect

• The framework we have developed gives a clear path to an understanding of the experimental data, and synthesis of ongoing uncertainty quantification efforts with data

Further work

• We are working towards a complete analysis of the full set of experimental data taken at the NIF so far.

• The linear response currently used it not justified for some nuisance parameters

• Careful understanding of the structure of the microphysics codes will also be essential

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See also recent work in “High Energy Density Physics” & “Nuclear Fusion”

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